

# EFFECT OF CERTAIN PLANT PARAMETERS ON PHOTOSYNTHESIS, TRANSPIRATION, AND EFFICIENCY OF WATER USE

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**ABSTRACT.**— Rates of gaseous exchange were measured on selected desert shrubs native to the northern Mojave Desert to determine effects of varying chamber temperature, CO<sub>2</sub> concentration, relative humidity, and root temperature in preliminary studies. Results indicate that changes in these parameters produced differences in the rates of photosynthesis and transpiration. *Ceratoides lanata* (Pursh) took up CO<sub>2</sub> almost equally at 25 and 39 C. Doubling the CO<sub>2</sub> concentration in the below-ambient range roughly doubled photosynthesis rates in *C. lanata*. Very small changes in relative humidity had marked changes in the photosynthesis and transpiration rates of four species studied, with greater effect on transpiration. Photosynthesis and transpiration increased, and water-use efficiency decreased in two species as soil temperature was increased from 9 to 29 C.

The subject of photosynthesis has been discussed and reviewed thoroughly by Sestak et al. (1971), Troughton (1975), and Cooper (1975). These reviews indicate that it is very difficult to predict or explain the photosynthetic rate of a plant because it is influenced by the simultaneous action of many external and internal factors that affect the rate of photosynthesis.

For this reason a study was undertaken with objectives to determine how sensitive the rates of CO<sub>2</sub> exchange and water loss are to variations in chamber temperature, CO<sub>2</sub> concentration, relative humidity, and the root temperature of the plant (i.e., how much variation can be tolerated in these parameters without adversely affecting the validity of gas exchange rates in desert plants). This technique has been described by Koller (1975).

Rates of photosynthesis and transpiration were measured using the Null-point Compensating System (Koller 1970) with the Improved Feedback Mechanism (Mork et al. 1972). The principle of this system is based on maintaining essentially constant conditions in the chamber; i.e., the CO<sub>2</sub> concentration, the relative humidity, the chamber temperature, and the bath temperature must be constant to make valid measurements of compensation rates.

## MATERIALS AND METHODS

Five species of desert shrubs were tested in February and March 1972: *Ephedra nevadensis* S. Wats., *Larrea tridentata* (Sesse & Moc. ex DC.) Cov., and *Lycium pallidum* Miers in the field, and *Atriplex hymenelytra* (Torr.) S. Wats., *Ceratoides lanata* (Pursh) and *L. tridentata* in the glasshouse.

Field plants were tested at various levels of CO<sub>2</sub> concentration. Plants in the glasshouse were tested at various chamber temperatures and root temperatures. Initially, a more complete and extensive study was envisioned, particularly with regard to the effect of varying the root temperature. All the necessary equipment was on hand: the plants were growing in water-jacketed lucite cylinders, so the root temperature could be adjusted by running heated or cooled water through the jacket. In each case one parameter was varied, and the rates of photosynthesis and transpiration were measured using the Null-point Compensating System with the Improved Feedback Mechanism. The light intensity was measured with a portable Weston meter. Air temperature has complex interactions with photosynthetic rate (Bauer et al. 1975, Mooney et al. 1975), but a study of them is not the purpose of this report.

The photosynthesis and transpiration rates

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were calculated using the method of Koller (1970) and expressed as mg CO<sub>2</sub> per g dry tissue per h (or as mg CO<sub>2</sub> per sample per h) and g H<sub>2</sub>O per g dry tissue per h (or as g H<sub>2</sub>O per sample per h), respectively.

Efficiency of water use is a ratio of photosynthesis (g CO<sub>2</sub> fixed per unit time) to transpiration (g water lost per unit time)  $\times$  100 (percent).

## RESULTS AND DISCUSSION

Increasing the chamber temperature about 25 C tended to increase the rate of water loss up to 46 C for *C. lanata* at field capacity soil moisture (Table 1). The rate of photosynthesis was decreased at 46 C but not at 39 C relative to 25 C. A wide optimum range was indicated for these glasshouse-grown plants.

The CO<sub>2</sub> concentration in the chamber had significant effects on the plant process rates as expected (Table 2). Increasing the CO<sub>2</sub> concentration (range 90–375  $\mu$ l/l air) increased the CO<sub>2</sub> exchange for *L. pallidum* almost tenfold while reducing the water loss by about 10 percent. About the same range of increases in CO<sub>2</sub> increased the CO<sub>2</sub> exchange about fourfold for *L. tridentata*, with a reduction in water loss of about 10 percent. Doubling the concentration of CO<sub>2</sub> in these low ranges roughly doubled the rate of CO<sub>2</sub> exchange. Decreasing the relative humidity even by very small increments for *L. tridentata* and *E. nevadensis* tended to reduce the CO<sub>2</sub> uptake ( $r = +0.68$  and  $+0.99$ , respectively, for the two species) and increase the water loss rate (Table 3). In contrast, the net result of a slight decrease in relative humid-

TABLE 1. Effects of chamber temperature on photosynthesis and transpiration rates and on efficiency of water use of *Ceratoides lanta* grown in the glasshouse (3-9-72).

Hour of day	Chamber temperature C	Light intensity $\mu$ Einsteins m <sup>-2</sup> sec <sup>-1</sup>	Photosynthesis mg CO <sub>2</sub> /g-h°	Transpiration g H <sub>2</sub> O/g-h°	Efficiency percent
1230-1250	24.8	1206	6.89	0.46	1.50
0953-1013	30.8	446	3.45	1.31	0.26
1128-1148	37.0	1296	7.38	1.23	0.60
1023-1043	38.8	782	8.90	1.30	0.68
1100-1120	46.3	1229	3.10	1.84	0.17

\*Measurements made on potted plant, continuing study.

Chamber conditions: CO<sub>2</sub> concentration 320  $\mu$ liters/liter air; relative humidity 27.7 percent; root temperature 28 C.

TABLE 2. Effect of CO<sub>2</sub> concentration on photosynthesis and transpiration rates, and on efficiency of water use of *Lycium pallidum* (3-18-72) and *Larrea tridentata* (3-10-72) in the field (Rock Valley).

Hour of day	CO <sub>2</sub> concentration $\mu$ liter liter air	Light intensity $\mu$ Einsteins m <sup>-2</sup> sec <sup>-1</sup>	Photosynthesis mg CO <sub>2</sub> /g-h°	Transpiration g H <sub>2</sub> O/g-h°	Efficiency percent
<i>Lycium pallidum</i>					
1020-1040	90	2410	4.39	3.34	0.13
1100-1120	132	2460	13.6	3.37	0.60
1200-1220	172	2410	17.8	3.32	0.54
1240-1300	215	2370	25.2	3.22	0.78
1320-1340	260	2370	28.9	3.16	0.94
1420-1440	375	2280	38.3	2.90	1.32
<i>Larrea tridentata</i>					
1110-1120	90	2460	6.25	1.19	0.52
1130-1140	132	2410	6.97	1.17	0.60
1200-1140	172	2370	8.00	1.11	0.72
1300-1310	215	2370	9.25	1.10	0.84
1330-1340	368	2370	26.3	1.03	2.55

Chamber conditions: Temperature 25 C; relative humidity 28.0 percent; root temperature 18-19 C.

ity on *C. lanata* was an increase both in photosynthesis ( $r = -0.94$ ) and in water loss ( $r = -0.99$ ). For *L. pallidum* the effect on the rates was somewhat the same ( $r = +0.26$  for photosynthesis and  $-0.84$  for transpiration

with decreasing relative humidity).

In the experiment with root temperature, the range should have been extended up to perhaps 40 C or higher. The data in Table 4 (for the range 10 to 29 C) showed increases in

TABLE 3. Effect of relative humidity on photosynthesis and transpiration rates, and on efficiency of water use of *Lycium pallidum* (3-17-72), *Larrea tridentata* (3-19-72), *Ephedra nevadensis* (3-21-72) and *Ceratoides lanata* (2-3-72) in the glasshouse.

Hour of day	R.H. percent	Light intensity $\mu$ Einsteins $m^{-2} sec^{-1}$	Photosynthesis $mg H_2O/g-h$	Transpiration $g H_2O/g-h$	Efficiency percent
<i>Lycium pallidum</i>					
1413-1433	27.9	2370	28.1	3.55	0.79
1457-1507	26.8	2270	32.2	4.09	0.79
1537-1547	25.5	2010	26.9	4.08	0.66
<i>Larrea tridentata</i>					
1530-1540	27.8	2270	14.3	0.90	1.58
1558-1608	26.8	2010	9.25	0.95	0.97
1610-1620	25.0	2010	10.7	1.07	1.00
1630-1640	24.2	2010	9.25	1.14	0.81
<i>Ephedra nevadensis</i>					
1550-1600	28.3	1880	4.09	0.12	3.30
1628-1724	27.8	1250	3.32	0.13	2.57
<i>Ceratoides lanata</i>					
1330-1350	27.5	693	2.98	0.08°	3.77
1255-1315	26.6	850	3.12°	0.11°	2.96
1220-1240	25.5	890	4.02°	0.17°	2.34
1145-1205	24.0	1200	4.18°	0.20°	2.07

\*Values for *Ceratoides lanata* are  $mg CO_2/sample-h$  and  $g H_2O/sample-h$ .  
Chamber conditions: Temperature 25 C;  $CO_2$  concentration 330  $\mu$ liters/liter air.

TABLE 4. Effect of root temperature on photosynthesis and transpiration rates, and on efficiency of water use of *Larrea tridentata* (3-9-72) and *Atriplex hymenelytra* (2-29-72) in the glasshouse.

Hour of day	Root temperature C	Light intensity $\mu$ Einsteins $m^{-2} sec^{-1}$	Photosynthesis $mg CO_2/g-h^*$	Transpiration $g H_2O/g-h^*$	Efficiency percent
<i>Larrea tridentata</i>					
1550-1600	10-11	1030	2.94	0.27	1.09
1530-1540	12-14	1120	4.45	0.54	0.83
1500-1510	16-19	540	3.81	0.73	0.52
1430-1440	23-26	1030	4.83	0.71	0.69
1350-1400	28-29	1030	5.65	0.70	0.80
<i>Atriplex hymenelytra</i>					
1432-1442	9.2	715	11.4	0.52	2.19
1410-1420	10.0	625	13.1	0.67	1.96
1315-1325	16.8	1210	21.6	0.93	2.32
1305-1315	20.0	1270	21.7	1.02	2.14
1240-1250	23.1	1340	20.6	1.05	1.97
1225-1235	27.7	985	22.9	1.13	2.02
1125-1135	29.0	1340	26.1	1.14	2.29

\*Measurements made on potted plants, continuing study.  
Chamber conditions: Temperature 25 C;  $CO_2$  concentration 322  $\mu$ liters/liter air; relative humidity 27.7 percent.

both photosynthesis and transpiration for both *L. tridentata* and *A. hymenelytra* grown in the glasshouse. Water-use efficiency decreased as soil temperature increased, as has been observed elsewhere (Wallace 1970). The  $C_4$  plant, *A. hymenelytra*, had a 4.6-fold greater photosynthetic rate, a 2.9-fold greater water-use efficiency, and a 1.6-fold greater transpiration rate at 29 C root temperature than the  $C_3$  plant *L. tridentata*. At 10 C root temperature the  $C_4$  plant had 2.9-fold greater photosynthesis, 2.4-fold greater water use efficiency, and 1.24-fold greater transpiration. The apparent advantages of the  $C_4$  characteristics seem to decrease as soil temperature is decreased.

Changes in the  $CO_2$  concentration, the chamber temperature, the relative humidity, or the root temperature of the plant may produce tenfold differences in the gas exchange rates. Therefore, it is important to maintain each of these parameters as constant as possible when making observations in experimental tests.

#### LITERATURE CITED

- BAUER, H., W. LARCHER, AND R. B. WALKER. 1975. Influence of temperature stress on  $CO_2$ -gas ex-

- change. In J. P. Cooper, ed. Photosynthesis and productivity in different environments. Cambridge University Press, Cambridge and London.
- COOPER, J. P., ED. 1975. Photosynthesis and productivity in different environments. International Biological Programme 3. Cambridge University Press, Cambridge and London.
- KOLLER, D. 1970. Determination of fundamental plant parameters controlling carbon assimilation and transpiration by the Null-point Compensating System. Soil Sci. 14: 61-68.
- . 1975. Effects of environmental stress on photosynthesis-conclusions. Pages 587-589 in J. P. Cooper, ed. Photosynthesis and productivity in different environments. Cambridge University Press, Cambridge and London.
- MOONEY, H. A., O. BJORKMAN, AND J. BERRY. 1975. Photosynthetic adaptations to high temperature. Pages 138-151 in N. F. Hadley, ed. Environmental physiology of desert organisms. Dowden, Hutchinson & Ross, Inc., Stroudsburg, Pennsylvania.
- MORK, H. M., R. W. FARMER, AND K. A. FLYGAR. 1972. Improved feedback control for the Null-point Compensating System. Soil Sci. 114: 61-68.
- SESTAK, Z., J. CATSKY, AND P. G. JARVIS, EDs. 1971. Plant photosynthetic production: manual of methods. Dr. W. Junk N.V., The Hague.
- TROUGHTON, J. H. 1975. Photosynthetic mechanisms in higher plants. Pages 375-391 in J. P. Cooper, ed., Photosynthesis and productivity in different environments. Cambridge University Press, Cambridge and London.
- WALLACE, A. 1970. Water use in a glasshouse by *Salsola kali* grown at different soil temperatures and at limiting soil moisture. Soil Sci. 110:146-149.